Low-Cost and Recyclable Oxygen Carrier and Novel Process for Chemical Looping Combustion

DOE Kick-off Meeting

February 13, 2018

University of North Dakota

Envergex LLC

Barr Engineering

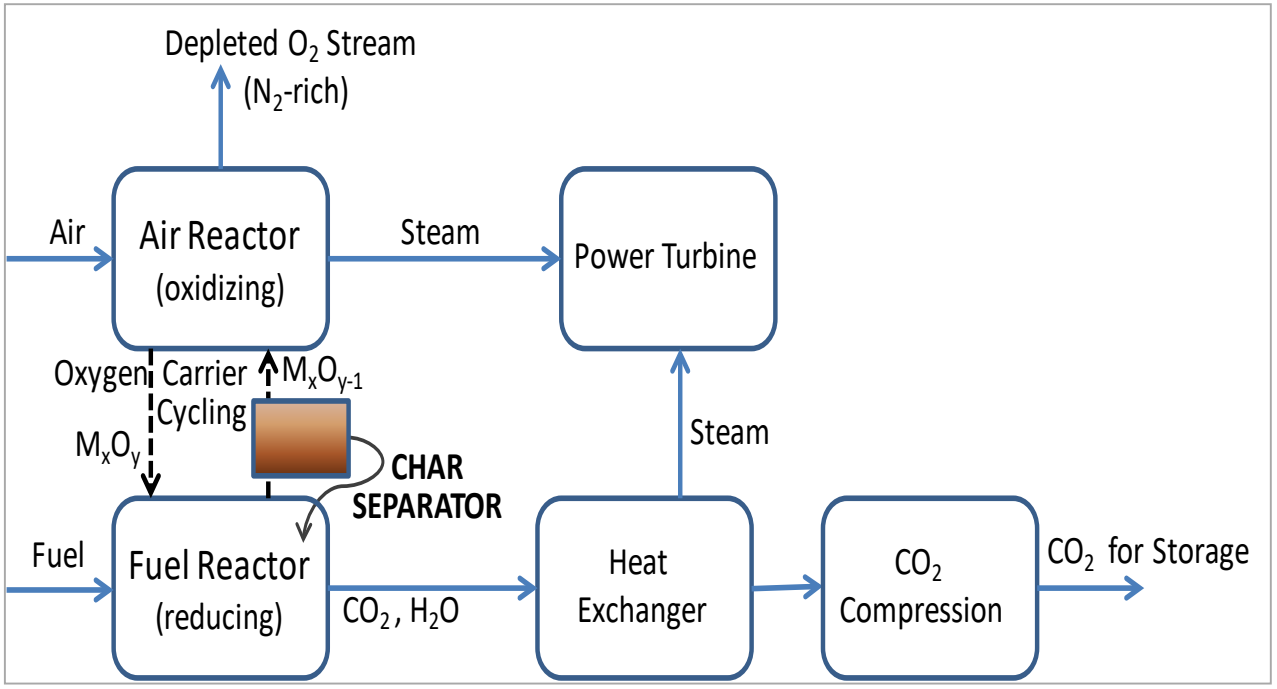
Microbeam Technologies, Inc

Carbontec Energy Corporation

Presentation Overview

- Brief Background on chemical looping combustion (CLC)
- Background on existing CLC projects at UND/Envergex
- Project Goals and Objectives
- Technical Approach
- Scope of Work
- Schedule and Deliverables
- Budget
- Project Management
- Questions/Discussion

Background on CLC



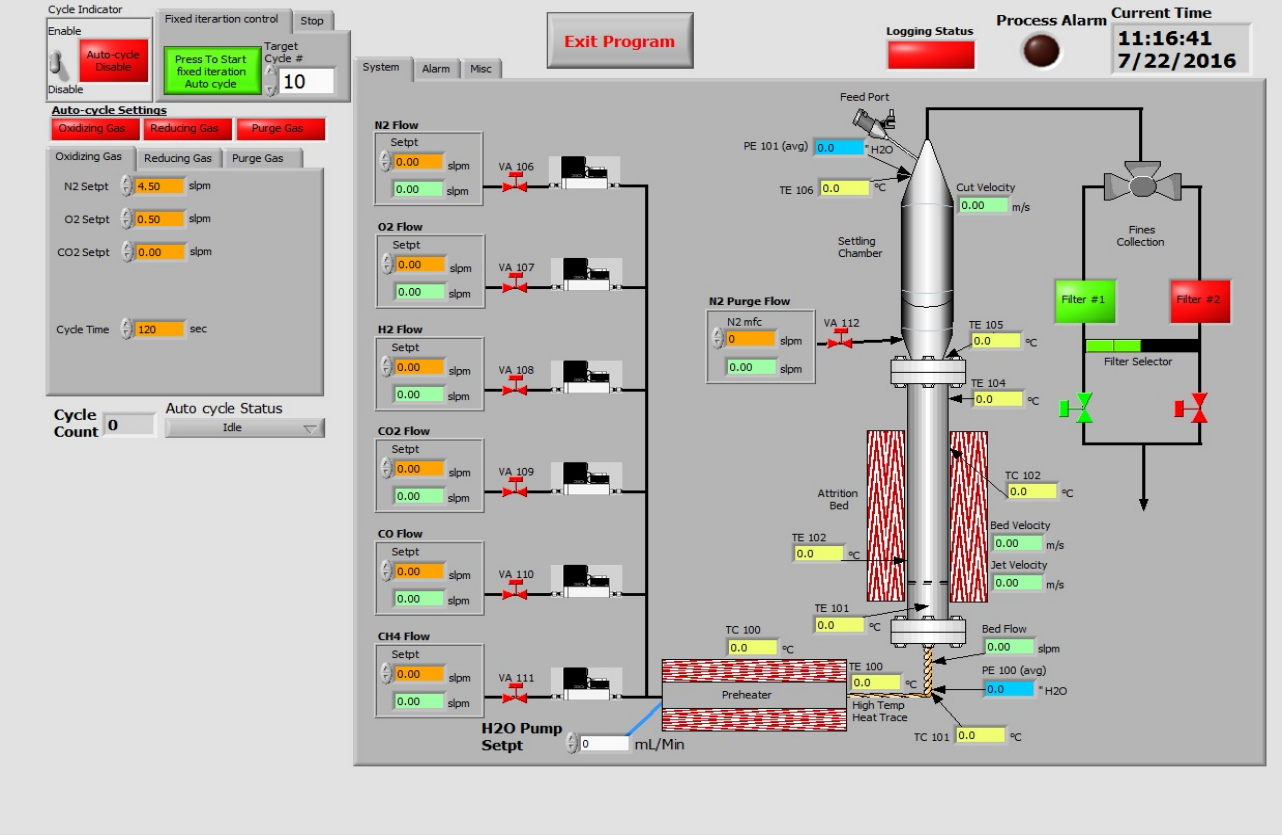
KEY ADVANTAGES OF CLC:

- In-situ CO_2 capture – decreased cost compared to plants with post-combustion systems
- Oxygen for fuel provided by metal oxide – no separate oxygen separation needed

KEY CHALLENGES FOR CLC:

- Oxygen carrier (OC) replacement costs – physical attrition, loss of reactivity, agglomeration
- Fuel conversion – solid carbon carryover to oxidizer, oxygen demand in reducer exhaust

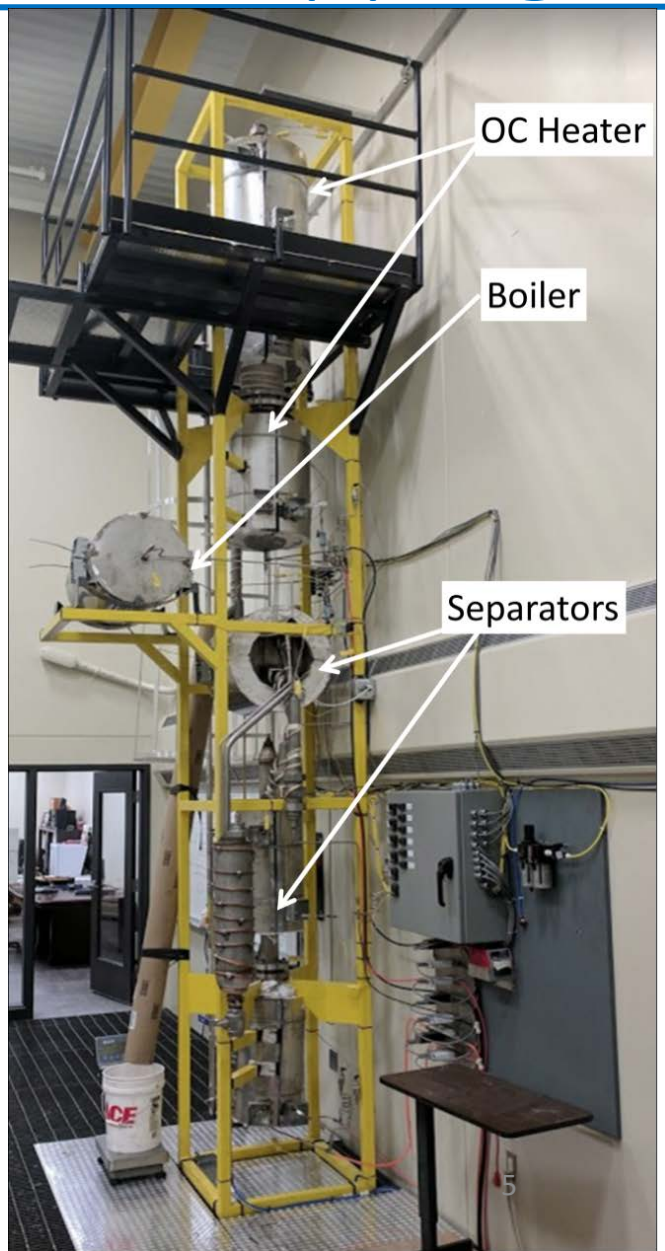
Existing Projects – OC Characterization



- Developed novel equipment and test methodology to quickly evaluate attrition and reactivity characteristics of OCs for CLC
- Goal to identify OCs with maximum lifetime and ability to ensure high/complete fuel conversion
- Developed large knowledge database

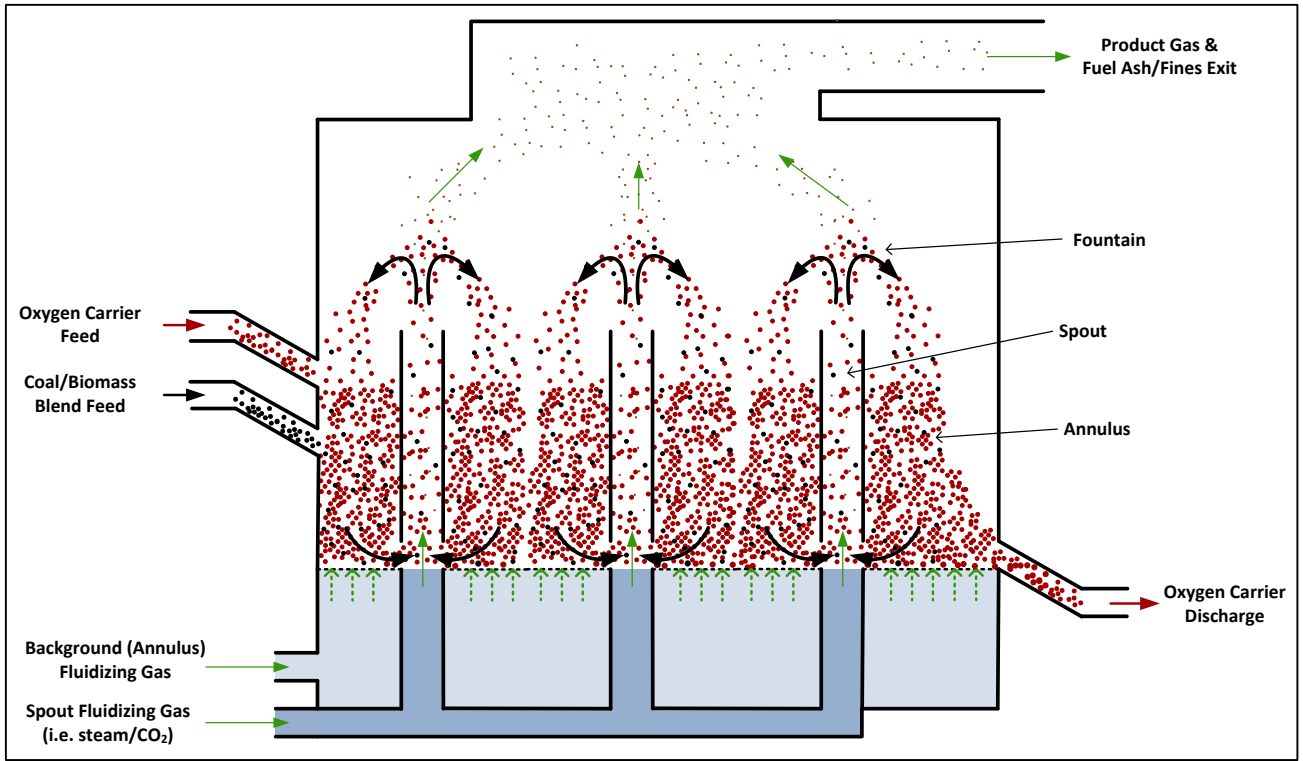
Existing Projects – Carbon Stripping

- In traditional reducer designs, unreacted char results in carbon slip to oxidizer and significant decrease in carbon capture efficiency
- Carbon stripping is likely a necessary component of the CLC process
- But a significant technical challenge
- OC attrition results in size fraction that cannot be separated from carbon by simple elutriation
- Envergex/UND PCS technology is a staged process with multiple separation mechanisms that overcomes this challenge (among others)



Existing Projects – Reducer Design

- The reducer must provide the following:
  - Sufficient OC/fuel contact time
  - Sufficient OC/reduced gas contact time
  - Operational robustness and flexibility
  - Scalability
  - Ability to provide good solids mixing and circulate solids effectively with low pressure drop
- Envergex/UND are evaluating a spouted fluid bed (SFB) design for the CLC reducer



Project Goals and Objectives

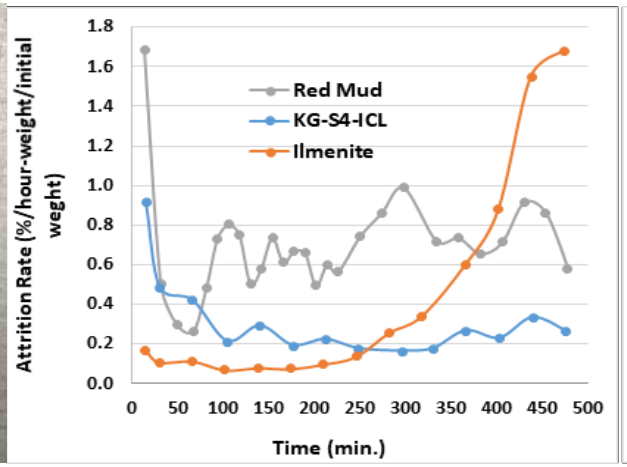
Overall Goal: Demonstrate transformational technology that overcomes two key CLC technology gaps:

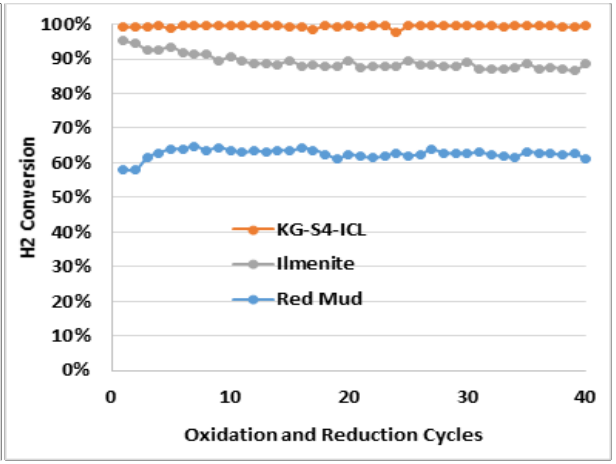
- high cost of OC replacement/loss
- incomplete fuel conversion, resulting in reduced CO_2 capture efficiency and an oxygen demand downstream of the CLC reducer reactor.

Specific Objectives:

- Demonstrate novel OC manufacturing platform: high performance of "engineered" OCs, but with cost structure of natural ores
- Demonstrate economic recyclability of OC fines
- Identify OC phase transformations and interactions with coal impurities that could impact OC/process performance and OC recyclability; identify mitigation strategies
- Test a novel combination of CLC components at the 10 kW_{th}-scale
  - OC, SFB Reducer, PCS Carbon Stripper, Novel Process Configuration
- Perform economic assessment to demonstrate progress towards DOE cost of CO_2 capture and cost of electricity targets.

Technical Approach – Overall Process





- Use unique hydrodynamics available with the SFB reducer design
  - Thermodynamics limits combination of fuel gas conversion and deep OC reduction
  - Counter-current operation of the annulus in the SFB can help to overcome this limit
  - Goal to cycle between Fe_2O_3 and FeO → 1/3 circulating load compared to Fe_2O_3 to Fe_3O_4
- Incorporate the PCS carbon stripper technology
- Goal: 90% CO_2 capture with no/minimal reducer exhaust oxygen demand
- Unique oxygen carrier composition and manufacturing platform
  - Main component enriched iron oxide powder: abundant and low-cost domestic production
  - Blending in a small proportion of low-cost additives to avoid agglomeration tendency of pure iron oxide
  - Low-cost manufacturing that is compatible with simple reformulation/recycle of OC fines caused by attrition

Scope of Work

- Task 1 – Project Management and Planning
- Task 2 – Laboratory-scale OC Manufacturing & Assessment
- Task 3 – Modeling and Laboratory-scale Evaluation of OC Performance with Coal
- Task 4 – 10 kW_{th} Integrated System Installation
- Task 5 – Scaled-up OC Manufacturing
- Task 6 – 10 kW_{th} Testing
- Task 7 – Process Design and Techno-Economic Analysis

Task 2 Overview

Subtask 2.1 – OC Manufacturing

- ~40 unique OC formulations
- Composition, binder loading, particle size, granulation method, curing

Subtask 2.2 – OC Characterization and Performance Testing

- Determine physical/chemical characteristics before/after exposure to CLC tests
- Perform CLC testing: reducing gas conversions, impact of sulfur, attrition, agglomeration
- Parameters to include: temperature, gas/solid contact time, reducing gas composition, jet velocity
- Down-select to 2 OCs based on testing

Subtask 2.3 – Longer-term Operation and Recyclability Evaluation

- ~500 redox cycles; evaluate performance and OC characteristics as fn(t)
- Collect fines generated and perform multiple reformulations; evaluate CLC performance/characteristics compared to fresh OC and as function of reformulation number

Task 3 Overview

Subtask 3.1 – Fluidized Bed Testing with Coal

- Use coal as reductant instead of reducing gases
- Parametric and longer-term testing
- Down-select to 1 OC formulation

Subtask 3.2 – Experimental Evaluation of OC/Coal Ash Interactions

- TGA-DSC: Identify zones of phase transformations/reactions of OC/coal ash; characterization to determine OC transformations
- Temperature, contact time, gas phase composition, ash type/composition

Subtask 3.3 – Thermochemical Equilibrium Modeling

- HSC Chemistry 9.0: model reactions of OC with coal ash
- Investigate agglomeration potential using viscosity models
- Develop mitigation strategies to minimize detrimental impacts

Subtask 3.4 – OC Fines Separation and Recyclability

- Tests to identify impact of coal impurities on OC recyclability

Tasks 4-6 Overview

Task 4 – 10 kW_{th} System Installation

- Leverage existing and to-be-constructed equipment from existing projects
- SFB reducer, PCS carbon stripper, Novel process configuration
- Circulating CLC system

Task 5 – Scaled-up OC Manufacturing

- ~1000 kg of down-selected OC formulation
- Evaluate physical/chemical characteristics to compare to lab quantities

Task 6 – 10 kW_{th} Testing

- Reducer/oxidizer temperature, OC residence time
- Reducer coal/char residence time
- OC/Coal ratio
- ~100 hours of testing at optimized conditions for two coal types

Task 7 Overview

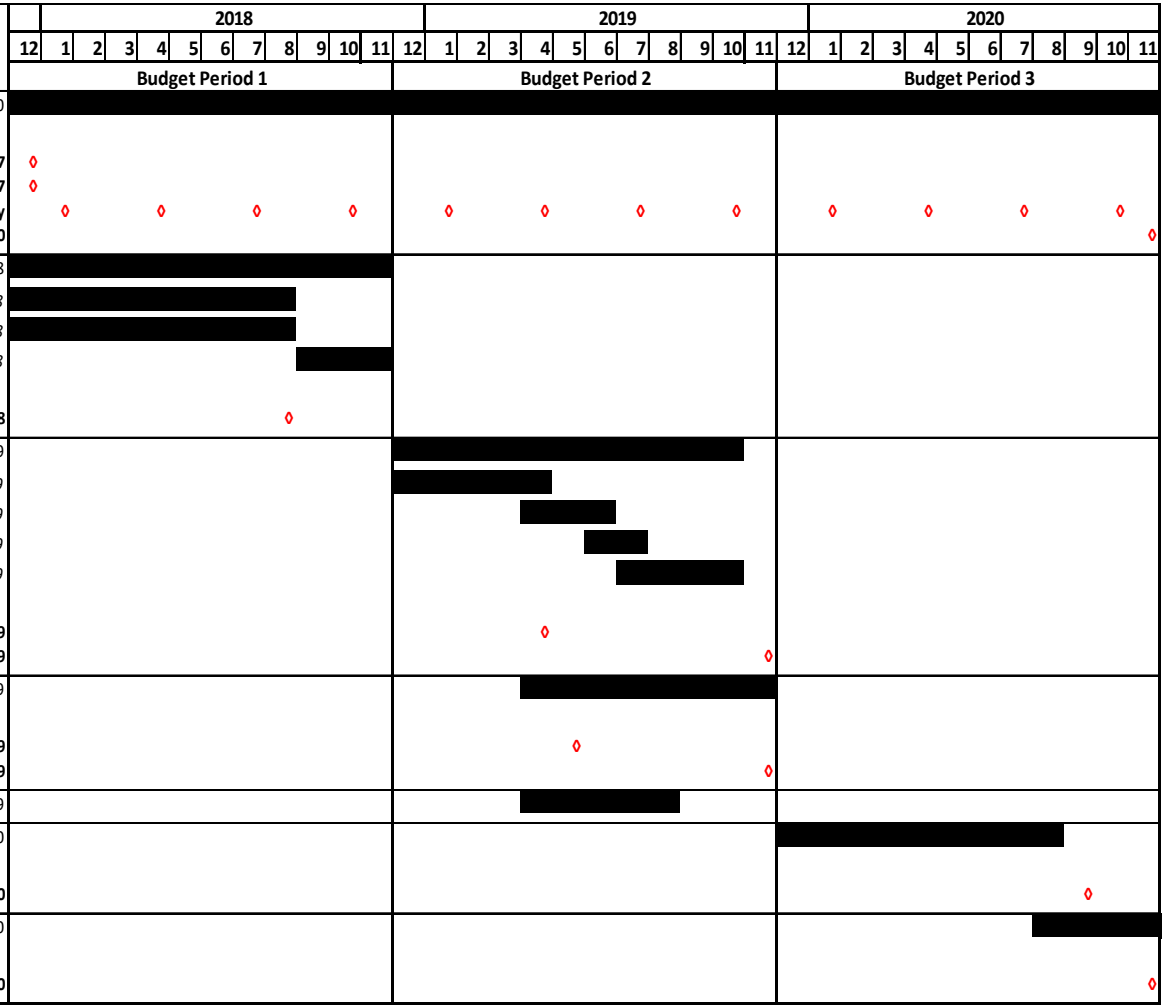
Task 7 – Process Design and Techno-Economic Assessment

- Benchmark: NETL's Reference Plant Designs and Sensitivity Studies (Stevens et al 2014)
- Process modeling using Aspen Plus®
- Determine economic metrics
- Led by qualified 3rd party A&E Firm – Barr Engineering Company

Stevens, R. et al., 2014: "Guidance for NETL's Oxy-combustion R&D Program: Chemical Looping Combustion Reference Plant Designs and Sensitivity Studies," DOE-NETL Report 2014/1643

Project Schedule

Task/Subtask/Milestone Description	Start Date	End Date
Task 1 - Project Management & Planning	12/01/17	11/30/20
Milestones/Deliverables		
Update Project Management Plan		**12/31/17**
Kickoff Meeting		**12/31/17**
Quarterly Report		**Quarterly**
Final Technical Report		**11/30/20**
Task 2 - Lab-scale OC Manufacturing & Assessment	12/01/17	11/30/18
Subtask 2.1 - OC Manufacturing	*12/01/17*	*08/31/18*
Subtask 2.2 - OC Characterization and Testing	*12/01/17*	*08/31/18*
Subtask 2.3 - Long-term Cyclic Testing and Recyclability Evaluation	*09/01/18*	*11/30/18*
Milestones/Deliverables		
Down-selection to about two OC types		**08/31/18**
Task 3 - Modeling and Laboratory-scale Evaluation of OC Performance with Coal	12/01/18	10/31/19
Subtask 3.1 - Fluidized Bed Testing	*12/01/18*	*04/30/19*
Subtask 3.2 - TGA Testing	*04/01/19*	*06/30/19*
Subtask 3.3 - Thermodynamic Modeling	*06/01/19*	*07/31/19*
Subtask 3.4 - OC Fines Separation and Recylability	*05/01/19*	*08/31/19*
Milestones/Deliverables		
Down-selection to at least one OC type		**04/30/19**
OC Characterization and Testing Summary Report		**11/30/19**
Task 4 - 10 kWth Integrated System Installation	04/01/19	11/30/19
Milestones/Deliverables		
System Design Package Report		**05/31/19**
System Commissioning		**11/30/19**
Task 5 - Scaled-up OC Manufacturing	05/01/19	08/31/19
Task 6 - 10 kWth Testing	12/01/19	08/31/20
Milestones/Deliverables		
10 kWth Testing Summary Report		**09/30/20**
Task 7 - Process Design and Technical and Economic Analysis	08/01/20	11/30/20
Milestones/Deliverables		
Technical and Economic Analysis Report		**11/30/20**



Milestones & Deliverables

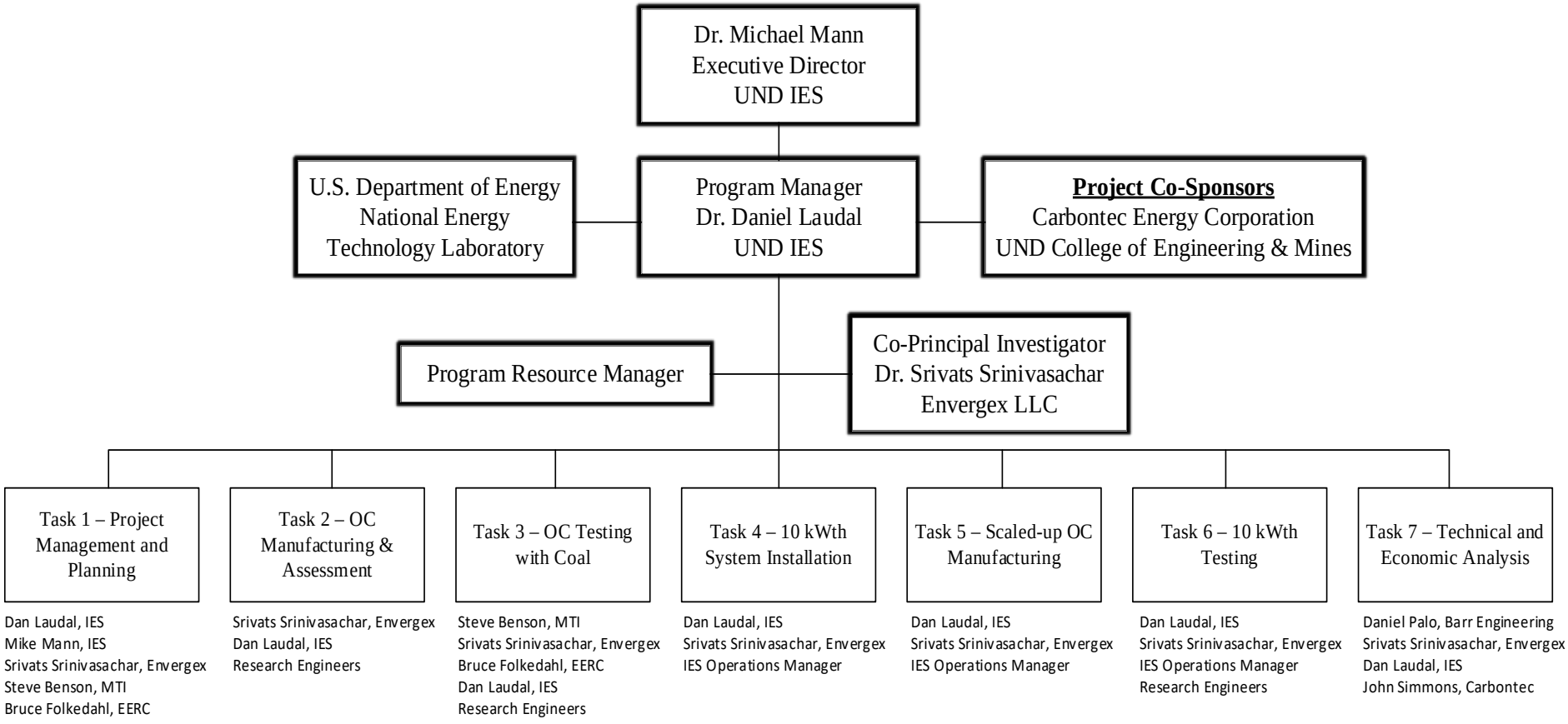
Budget Period	ID	Task Number	Description	Planned Completion End of month	Actual Completion Date	Verification Method
1	D1	1	Update PMP	12/31/17	02/21/18	PMP File
1	a	1	Kick-off meeting	12/31/17	02/13/18	Web-Ex
1	b	2	Down-selection to about two OC types	08/31/18		Quarterly Report
1	c	3	Down-selection to at least one OC type	04/30/19		Quarterly Report
2	D2	4	10 kW_{th} System Design Package Report	05/31/19		Report File
1	D3	3	OC Characterization and Testing Summary Report	11/30/19		Report File
2	d	4	10 kW_{th} Commissioning	11/30/19		Quarterly Report
3	D4	6	10 kW_{th} Testing Report	09/30/20		Report File
3	D5	7	Techno-Economic Analysis Report	11/30/20		Report File
3	D6	1	Final Technical Report	11/30/20		Report File

Project Budget

Recipient Organization	DOE Funds	Non-Federal Cost Share	Total
University of North Dakota	1,035,000	250,000	1,285,000
Envergex LLC	375,000	0	375,000
Barr Engineering	90,000	0	90,000
Carbontec (in-kind cost share)	0	125,000	125,000
Total ($)	1,500,000	375,000	1,875,000

Note: Request pending to add Microbeam as new subcontractor

Project Management



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Questions/Discussion

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